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Variable Shape Attitude Control Demonstration with Microsat "Hibari"

Kenichi Sasaki, Yuhei Kikuya, Sho Koizumi, Yuto Masuda, Yusuke Shintani, Tsubasa Tsunemitsu, Takashi Furuya, Yohei Iwasaki, Yuichiro Takeuchi, Kei Watanabe, Saburo Matunaga
Dept. Mechanical Engineering, School of Engineering, Tokyo Institute of Technology (which is same for all)
2-12-1, Ookayama, Meguro, Tokyo, 152-8552 (which is same for all), Japan;
+81 3 5734 2609
sasaki@lss.mes.titech.ac.jp

Yoichi Yatsu, Toshiki Ozawa
Dept. of Physics, School of Science Tokyo Institute of Technology (which is same for all)
2-12-1, Ookayama, Meguro, Tokyo, 152-8552 (which is same for all), Japan;
+81 3 5734 2388
yatsu@hp.phys.titech.ac.jp

ABSTRACT

This paper presents the ongoing feasibility study and bus system for microsatellite "Hibari". The main technical missions for Hibari is called "Variable Shape Attitude Control (VSAC)". This VSAC is based on an idea to utilize a reaction torque when a part of the satellite structure, for example, solar array paddles is appropriately rotated by actuators. The previous research concluded that VSAC successfully achieved the rapid maneuvering while maintain the high attitude stability against disturbances [1], and thus, it can be applied to a variety of advanced attitude control missions. Hibari project also aims at its application to astronomical mission requiring high pointing stability and agile maneuvering. This paper is mainly comprised of 3 parts: detail mission statement, ongoing feasibility studies and bus system configuration. First, we mention the mission requirement and detail mission sequence for both technical and science missions. Second, we show the ongoing feasibility studies to confirm that all mission requirement is satisfied by VSAC. Third, this paper describes each subsystem configuration to meet the system requirement stated in the mission's section. And then, we wrap up in the conclusion section and stated the future study for advanced VSAC use in the end.

INTRODUCTION

In recent years, increasing number of microsatellite and cubesat was launched especially by startups and academic institutions. Even these small-sized satellites realize advanced missions such as earth observations and science missions, which used to be achieved only by large satellites a few decades ago. Those can take advantages of lower cost and shorter period of time for satellite development which best suits to the demonstration of advanced missions.

Matunaga Lab. at Tokyo Institute of Technology focuses satellite development on attitude control missions. For example, we developed TESUBAME microsatellite to achieve the agile maneuvering by CMG [1]. One of the authors [2] proposed a new attitude control system (ACS) concept: Variable Shape Attitude Control (VSAC) in 2016. Our team started a microsatellite project called "Hibari" demonstrating VSAC method on orbit. Hibari project also aims at its application to astronomical missions. Hibari project is currently under the stage of conceptual design and evaluating the results of feasibility study. This paper will present the engineering mission of the Hibari and the ongoing feasibility study result for mission requirements and bus system.

MISSION

Hibari mission is mainly 2 folds: on-orbit VSAC demonstration and an observation of gravitational wave (GW) sources.

Technical Mission

The main technical mission is on-orbit VSAC demonstration. VSAC is a method for attitude control system and based on an idea to utilize a reaction torque when a part of the satellite structure, for example, solar array paddles is appropriately rotated by actuators as shown in Figure 1. The previous research concluded that VSAC successfully achieved the agile maneuvering while maintain the high attitude stability against disturbances in a simulation testbed [2]. VSAC is expected to simultaneously satisfy both agility and stability for satellite's attitude whereas other actuators such as reaction wheel (RW) and control moment gyro (CMG) is difficult to achieve both requirement at once.

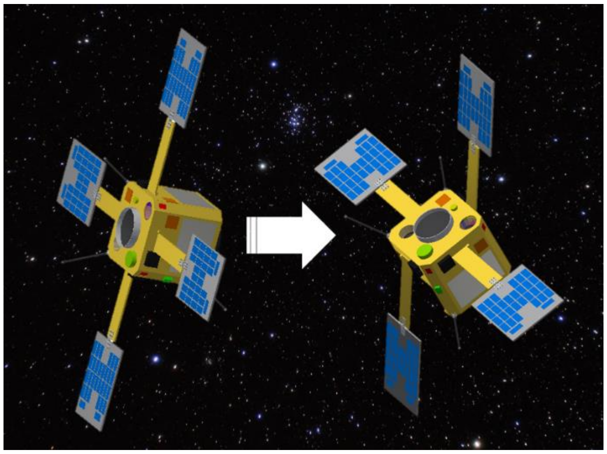

Figure 1: Concept of VSAC

Mission Sequence

In addition to the technical mission, Hibari project also aims at its application to astronomical mission which observes the transient astronomical object such as GW sources. Therefore, Hibari satellite is deployed a telescope for this mission and the observation is synchronized with ground observatories. The detail science mission is described in the reference [3].

Figure 2 shows the overview of the mission sequence for GW detection. First, after our ground station receives an alert from ground GW interferometers, we promptly uplink a command to start follow-up observation to Hibari satellite via IRIDIUM communication system (mentioned in SYSTEM CONFIGURATION's section). Thus, telescope mounted on the satellite has to direct to an arbitrary direction or area that is most likely to have GW sources in a best effort time (within 300s). The agile maneuvering by VSAC makes those immediate catch-up observation mission possible. Also, the pointing stability is required during the observation of GW sources (within 10 $arcsec^2$).

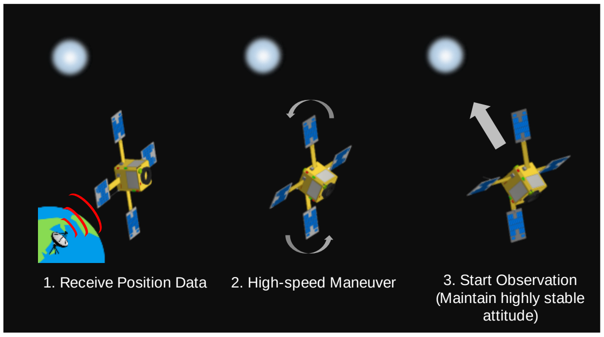

Figure 2: Overview of mission sequence

MISSION ANALYSIS

As the mission sequence is described in a previous section, Hibari is required high stability (< 10 $arcsec^2$) and agile maneuvering (< 300s). In order to achieve these requirements, Hibari has two kinds of attitude control actuators: VSAC and RW. The former is used for agile maneuvering by driving solar array paddles and the latter is for stabilizing the satellite's attitude to compensate disturbances such as atmospheric drag force, residual magnetic torque and gravity gradient torque. Thus, our team established the numerical simulation testbed which modeled the VSAC and RW dynamics and disturbances that is mentioned above. The detail control logic of VSAC and RW is mentioned in the past paper [2].

Simulation Setup

The configuration for the feasibility study is determined as is shown in Figure 3 and Table 1. Maneuver angle is set as $\theta = 30\text{deg}$, $\emptyset = 30\text{deg}$ as shown in Figure 4 and paddle maximum rotation speed is set as 10 degree/s. Also, we utilized 3 Blue Canyon's RWs enclosed in ADCS module: XACT (mentioned in detail in SYSTEM CONFIGURATION's section). In this simulation, RW and VSAC are supposed to be driven ideally and not considered any disturbances such as vibration.

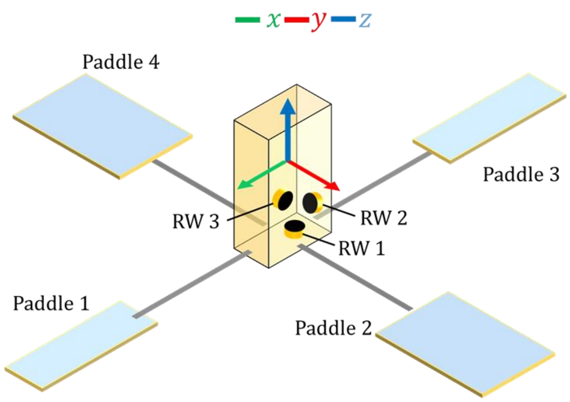

Figure 3 Satellite Configuration for Simulation:

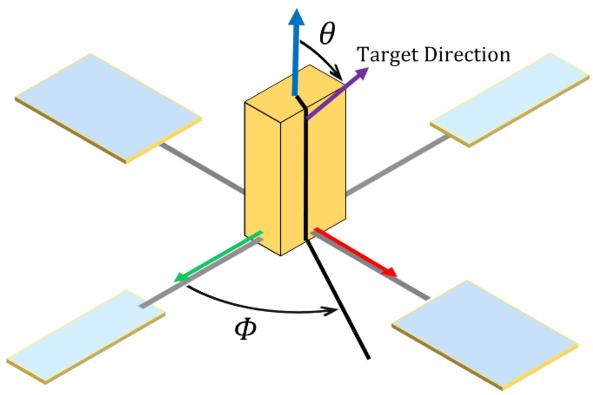

Figure 4: Maneuver Angle Definition

Table 1: Satellite Size and Weight for Simulation

	Mass[kg]	Dimension[m]
Main Body	6	0.1*0.2*0.3
Paddle1, 3	0.2	0.1*0.3
Paddle2, 4	0.4	0.2*0.3
Rod	0.1	0.3
RW	0.13	R: 0.021 H: 0.019

Simulation Result

Figure 5 through Figure 11 shows time history data of each state in RW and paddles calculated by that simulator . Maneuvering has conducted in 13.8 seconds which successfully achieved the mission requirement. We can also see from Figure 6 that the required torque to implement this paddle rotation is roughly 0.02 Nm, which is feasible to be generated by practical motors and gears. Paddles are also rotated within the range of physical angle limitation: 90 degrees as shown Figure 7. When the paddles are driven after the main body is rotated, z axial angular momentum is generated which the main body unintentionally have. Figure 8 explains that z axial angular momentum is compensated with RW to maneuver the main body in a fastest time. Error angle, on the other hand, decreased to 1×10^{-3} degrees in around 40 seconds as is shown in Figure 9 and its zoomed one: Figure 10. This is also expected to achieve the science mission stability requirement ($< 10\ arcsec^2 = 2.78 \times 10^{-3} deg$). As for the main body of Hibari satellite, the angular velocity is settled right after the paddle rotations are ended, which is also expected to achieve stabilized maneuvering. As it is discussed, the agile and stable maneuvering is successfully accomplished by implementation of VSAC and RW.

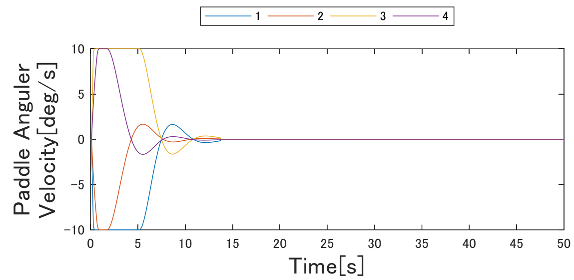

Figure 5: Time History of Paddle Angular Velocity

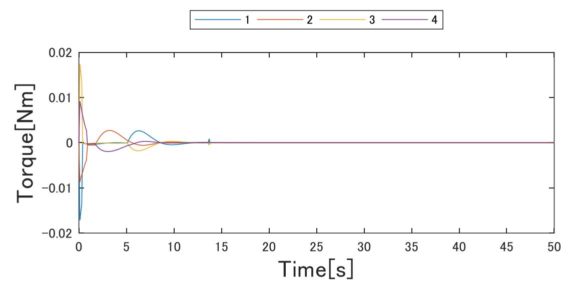

Figure 6: Time History of Required Torque for Paddles

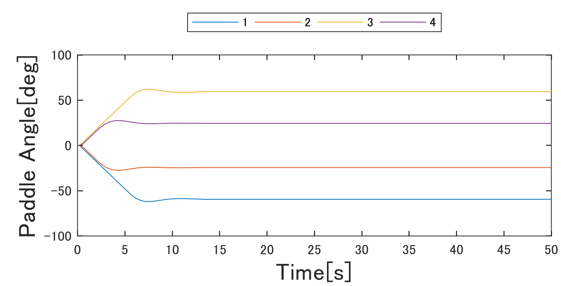

Figure 7: Time History of Paddle Angle

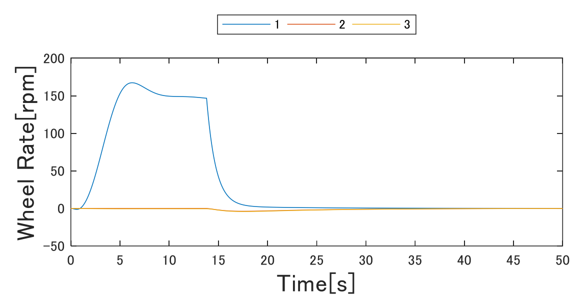

Figure 8; Time History of Wheel Rate

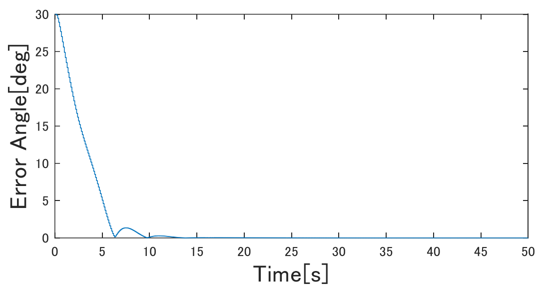

Figure 9: Time History of Error Angle

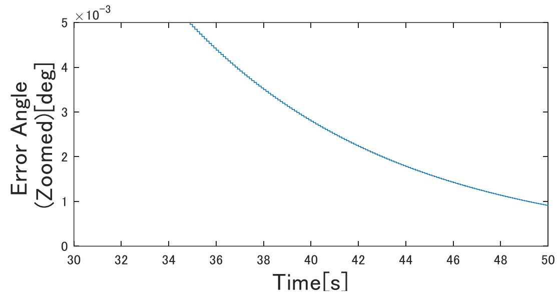

Figure 10: Time History of Error Angle (Zoomed)

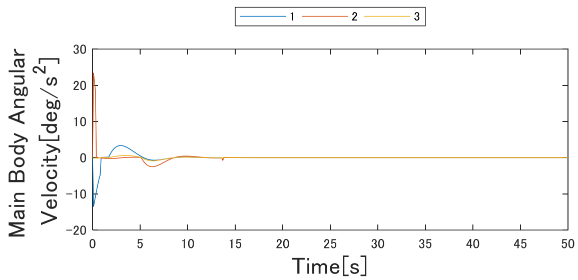

Figure 11: Time History of Main Body Angular Velocity

Furthermore, the maneuver simulation only by RW is also described below. RW and other satellite conditions are the same as the previous simulation. Note that the main body is not mounted rods between main body and paddles. Figure 12 and Figure 13 show the time history data of RW's wheel rate and satellite angular velocity respectively. It takes around 40 seconds to finish the maneuver. Hence, VSAC can achieve more agile maneuver compared with an attitude control by RW.

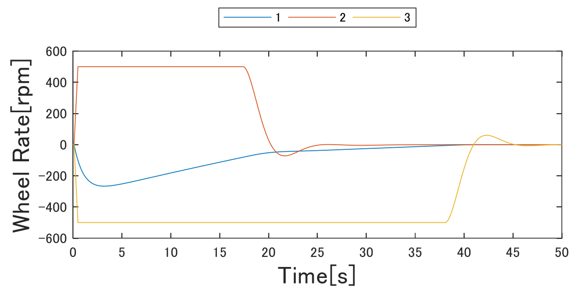

Figure 12: Time History of Wheel Rate (Only RW maneuver)

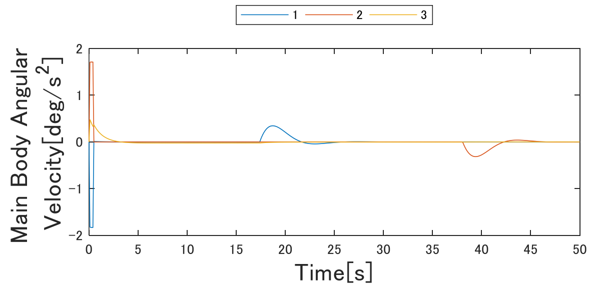

Figure 13: Time History of Main Body Angular Velocity (only RW maneuver)

SYSTEM CONFIGURATION

The bus system for VSAC demonstration is designed in 2016 for 50kg microsatellite due to the dimensional requirement for science mission in 2016. Since the telescope for science mission can be downsized and will be able to enclose it within 3U cubesat size, the bus system is currently under way of downsizing to 6U cubesat. The satellite system is comprised of 4 subsystems; Attitude Determination and Control system(ADCS), Communication/Command & Data Handling (Comm/C&DH), Electrical Power system(EPS) and Structure/Thermal. The rough bus system sketch is shown in Figure 14 and the system diagram is shown in Figure 15. Note that current design on the CAD sketch could not satisfy the full system requirement. Some of the components in Each subsystem planned to be purchased and integrated together in order to reduce the development time as long as they guarantee each reliability for subsystem components. As of now, Hibari satellite is considered to integrate with Blue Canyon Technologies' ADCS modules and ISIS communication circuit board. We have still been screening those components and contacting the manufacturing companies.

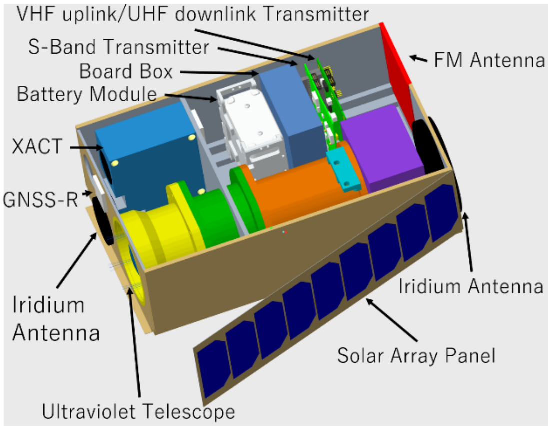

Figure 14: Bus System Rough Sketch

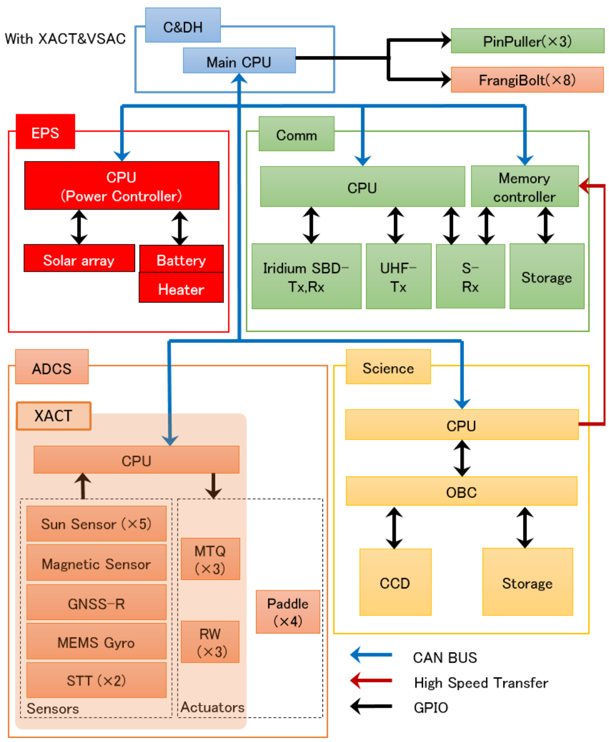

Figure 15: System Diagram

Communication & CDH

This avionics system is transceived the data via Controller Area Network (CAN) in order to guarantee high speed and low noise communications. As for Comm subsystem, Hibari satellite has 3 kinds of communication: S-band, Iridium and UHF/VHF. S-band transmitter is installed to downlink the science mission data as it's described in mission sequence section. Since we don't have any big-data receiving requirement, Hibari satellite is only attached the transmitter for S-band. In addition, UHF/VHF is utilized to handle the House Keeping (HK) data and IRIDIUM is also introduced to notify ground facilities when this cubesat detects the GW resource and vice versa. IRIDIUM is expected to enable us to communicate to cubesat once in every 30 minutes. Figure 16 shows the IRIDIUM transceiver [4]. As for UHF/VHF and S band transmitter, Hibari is planned to be deployed the ISIS products.

Figure 16: Overview of Iridium Transceiver[4]

EPS

The maximum power consumption including communication devices such as a S-band transmitter and mission components is expected to reach more than 30 W that requires for cubesat to deploy the solar array paddles to secure the power generation. As for EPS module, we're planning to apply Pumpkin Inc.'s battery and circuit board. Table 2 shows the estimated power consumption for each major components. Major components which are required high power consumption such as VSAC and science components and S-band is planned to be utilized simultaneously during the mission mode.

Table 2: Power Consumption Estimates

Components		Power	Nominal	VSAC	S-Band	Iridium
Sci	sensor	1	on	on	on	on
	FPGA	1	on	on	on	on
	OBC	3	on	on	on	on
	Cooling	5	on	on	on	on
	Heater	3	on	on	on	on
Subtotal		13	13	13	13	13
Eng	CDH	1	on	on	on	on
	FM	5	off	off	off	off
	S-band	10	off	off	on	off
	Iridium	1	on	on	on	on
	Xact	5	on	on	on	on
	VSAC	10	off	on	off	off
	EPS	1	on	on	on	on
Total[W]		46	21	31	31	21

ADCS

ADCS is going to be adopted a Blue Canyon Technology's ADCS module to realize the pointing accuracy and attitude stability. One of the Blue Canyon's module; XACT, which has 10 $arcsec^2$ pointing accuracy and sizes 0.5 U and 0.9kg [5], satisfies the requirement for both of bus system and science mission. Figure 17 shows the XACT overview. XACT has 4 ADS sensors: Sun Sensor, Magnetic Sensor, MESM Gyro and STT, and also has 2 ACS actuators: Magnetic Torquer (MTQ), Reaction Wheel (RW). Attitude determination and nominal attitude control is conducted by this XACT module. The agile large-angle maneuver is going to be achieved by implementing VSAC technique (technical mission).

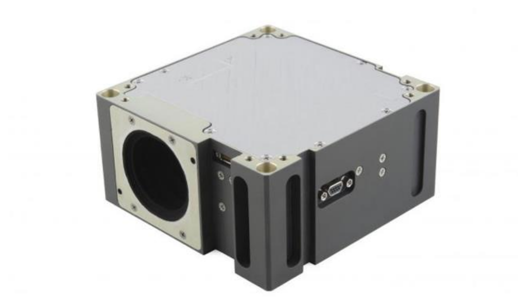

Figure 17: XACT overview[5]

Structure and Thermal

The main body frame is supported by the dividing panel in order to maintain the spacecraft structure, as it's shown in Figure 14, since the main body is hard to secure the rigidity by the enclosure due to the telescope dimensional requirements. Note that the Figure 14 only shows the rough sketch of components for bus system and VSAC mission related components are not depicted. VSAC's mechanism and structure is currently designing and detail size and weight will be also determined later.

As for thermal design, the main body surface is covered with silver Teflon and multi-layer insulation (MLI) to appropriately radiate the internal heat and reduce the temperature fluctuation inside the main body as shown in Figure 18. Solar cell array is attached on the solar array paddles to generate the enough energy for mission's mode which employ ultraviolet telescope, VSAC and Iridium/ S-band communication. Also, solar cell array is not mounted on the main body so that the enough silver Teflon is attached on the main body.

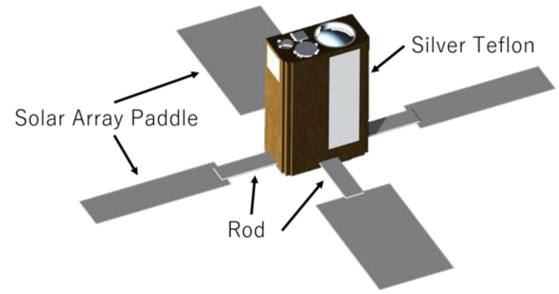

Figure 18: Expected overview of Hibari satellite

FUTURE STUDY

VSAC technique is expected to be utilized in various ways whereas Hibari satellite is developed to accomplish the agile maneuvering. One approach to suggest the other VSAC use is that changing or increasing the rotation axis can vary the attitude control directions and resolution range. It is expected to achieve the stable maneuvering by VSAC drive with 2 degree of freedom (DoF). 2 DoF VSAC driving is achieved by rotating the arms and revolute the solar array paddle in an orthogonal axis with an arm rotation axis as is shown in Figure 19. Y axis rotation is expected to achieve small torque maneuvering.

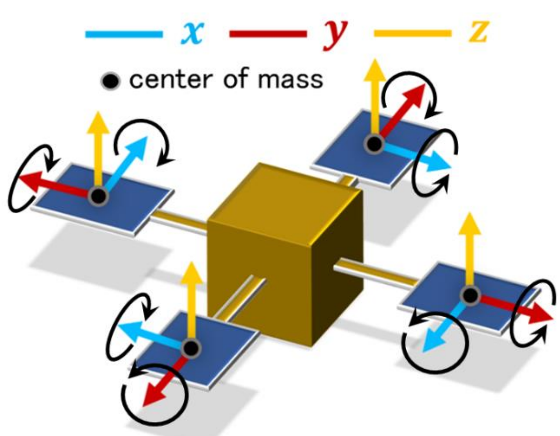

Figure 19: 2 DoF VSAC Overview

Our team also works for the application of driving paddles to an advanced use. One of the examples of the advanced missions with driving paddles is to control the orbit trajectory phase for formation flying by rotating the solar array paddles to utilize atmospheric drag force. Figure 20 shows the conceptual image of Hibari microsatellite to drive paddles to control the atmospheric drag force. Those microsatellites and cubesats are difficult to decide their desired orbit to be launched on, since they're typically launched with larger satellite as a piggyback launch. Therefore, this could be the essential technique to control the orbit for microsatellite or cubesat.

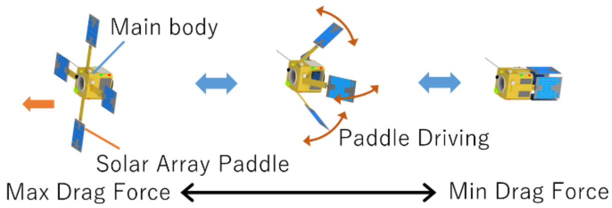

Figure 20: Conceptual Image of VSAC orbit control

CONCLUSION

This paper proposed Hibari satellite project that demonstrates the new attitude control method: Variable Shape Attitude Control. Hibari satellite also aims at its application to scientific mission that displays the availability for VSAC. In order to accomplish those missions, we set up the detail mission requirement and develop a simulation testbed. Through these feasibility studies, we successfully showed to be able to achieve the mission requirement by VSAC. In addition, the bus conceptual design is presented to realize these missions.

References

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